Determination of Natural Convective Heat Transfer Coefficient of Air over an Isothermal Surface

Amal Sajikumar[1]
amalsjkmr@gmail.com

Manu M. John[2]
Johnmanu007@gmail.com

Mathew Joseph[3]
mathewjoseph@amaljyothi.ac.in

Mechanical Engineering Department,
College of Engineering Adoor,
Kerala, India

***Abstract*—Natural convective haet transfer from flat surfaces and short cylinders in laminar regions with isothermal conditions have been experimentally studied. The experiments are not conducted in constant heat flux boundary condition. The measure of heat transfer is based on Nusselt number and heat transfer coefficient. The experiments are conducted for different orientations and shape. There is an enhancement of 300% in Nusselt number from horizontal orientation to vertical orientation. Also the effect of shape is studied in this experiment.**

***Index Terms*—Isothermal surface, constant heat flux, Nusselt number**

I. INTRODUCTION

There are so many studies done in natural convection over isothermal flat surfaces. The flat surfaces are heated to a particular temperature by using a heater and after attaining a steady state it temperature readings are noted and calculations are done. Instead of this heater setup, we are conducting a study on ice block. Here ice block is assumed as isothermal flat surface. Studies are conducting for different orientation and shape of the ice block. The orientation and shape may strongly influence the flow and heat transfer rate. Therefore there is a need for additional research to predict the heat transfer rates from such narrow flat surfaces and short cylinder and to clarify the significance. In the recent years, to find the convective heat transfer coefficient an experimental setup consisted of 4 main parts, glass water reservoir, a vertical Aluminum flat plate, a heating system, a data acquisition system is used. It was verified a good agreement among the experimental, the numerical and the analytical results for both laminar and the beginning of transition regimes [1]. There isanother experiment to find the heat transfer rate over a horizontal isothermal circular disc and to develop a dimensionless correlation for natural convection for a wide range of Rayleigh number [2]. In 2013 an experimental study of steady state natural convection heat transfer from vertical, horizontal and inclined heated cylinder with different cross sections situated in a vented enclosure, opened from the top and the bottom are investigated [3]. The maximum value of the average heat transfer coefficient occurs in the horizontal position (θ=0º) and the minimum value in the vertical position (θ=90º), for the same heat input and aspect ratio. In the study by comuneia et al they conduct an experiment to determine the influence of neighborhood on the convective heat transfer. Setup consists of a vertical plate (copper), heater, and Heat fluxmeters. Experiment begins when steady state is attained [4]. They concluded that Heat transfer coefficient increases as the plate width decreases. With lowest plate width used, the heat transfer coefficient was about 150% above than for the widest plate. From the literature review, it was seen that most of the studies are conducted on heated plates and finding out the convective heat transfer coefficients. Our aim is to make a low cost natural convection setup using isothermal flat surfaces and short cylinders. An ice block of specified dimension is used as the isothermal flat surface and to determine the convective heat transfer coefficient (h), by natural convection of air over an ice block in different orientations and shape. The objective of the project is to find and compare the value of heat transfer coefficient experimentally. Experimental result for various orientations and shape is compared and analyzed.

II. EXPERIMENTAL SETUP

An experimental test facility is constructed to measure the heat transfer coefficient in two orientations and a cylindrical shape. The sketch of test facility is as shown in fig (1) and photograph of experimental set up is as shown in fig (2). The experimental setup consists of mainly 6 parts:

TABLE I.

SPECIFICATION OF EXPERIMENTAL SETUP

Item	**Specification**
Cylindrical Container	320X320 mm
Ice Block	120 X 75 X 35 mm
Funnel	Mouth dia: 80 mm
Metal Wire	Length: 250 mm Material: Steel
Thermometer (3 Nos)	Range: -10° C to 110° C
Measuring Flask	50 ml

Experiment is mainly done in two orientations. Rectangular Ice block is placed horizontally and vertically. Experiment is also conducted by taking same volume of water in a cylindrical container. The setup is shown below.

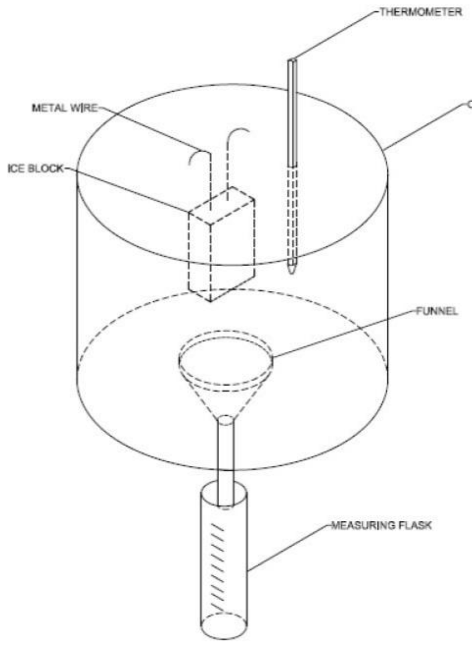

Figure 1. Schematic diagram of experimental setup

Figure 2. Photographs of experiment

A. Experimental Procedure

Note the ambient temperature of the surroundings before starting the experiment. Set up the experiment as shown in the figure 1. Before starting the experiment, ensure that the container is airtight. Start the stopwatch. Note the time for collecting 3ml of the melted ice. Note the temperatures shown by the thermometers inside the container as T.Continue the experiment till the 30ml of melted ice is collected. Record the time and temperature for every 3ml collection of melted ice. Stop the stopwatch when 30ml is collected inside the measuring flask. Tabulate the results. Using the time mass flow rate is calculated and from this the experimental value of heat transfer coefficient (h) could be calculated. A flow simulation for the flow of air over the vertical plate is done and the values obtained from that is also used to find the heat transfer coefficient. The experiment was repeated for horizontal flat plate and cylinder shape. The value obtained experimentally are compared and analyzed.

III. DATA REDUCTION

Mass of water collected in the beaker (m_{wcb})

$$m_{wcb} = \rho_w * vol_{wcb} \quad (1)$$

Where ρ_w = density of water in kg/m^3

vol_{wcb} = volume of water collected in the beaker (3ml)

Mass flow rate ($\dot{m}_w$)

$$\dot{m}_w = \frac{m_{wcb}}{t} \quad (2)$$

Where t = time taken for 3ml melting of ice in seconds

Actual heat transfer rate (Q_{act})

$$Q_{act} = \dot{m}_w * L_w \quad (3)$$

Where L_w = latent heat of vaporization of ice in Kj/Kg

Heat transfer coefficient (h)

$$h = \frac{Q_{act}}{A\Delta T} \quad (4)$$

Where A = surface area of ice

ΔT = temperature difference of isothermal surface and air

Rayleigh number can be determined by

$$Ra = Gr * Pr \quad (5)$$

Where Ra is the Rayleigh number, Gr is the grashof number and Pr is the prandtl number

$$Gr = \frac{g\beta L^3 \Delta T}{\nu^2} \quad (6)$$

Where g is acceleration due to gravity, β is coefficient of thermal expansion, L is the characteristic length and ν is the kinematic viscosity.

The Nusselt number (Nu) is calculated in terms of heat transfer coefficient, characteristic length (L) and thermal conductivity (k) as

$$Nu = \frac{hL}{K} \quad (7)$$

IV. RESULTS

The objectives of the present work were to study the convective heat transfer in different orientations of ice block and shape. For that the experiment is conducted for horizontal, vertical orientation of rectangular ice block and a cylindrical shape with different Rayleigh number flow. From the result the Nusselt number is increasing by increasing the Rayleigh number because for more turbulent in high Rayleigh number flow and hence the heat trance rate become more. And as a result the surrounding temperature of air is decreasing as Rayleigh number increase. Here the maximum value of Ra in vertical position of ice block is 4600000. For that value of Nu is obtained as 40. For horizontal variation Ra value is in the range of 10^5. So Nu value is decreased to 10. In case of cylindrical shape these values are in between the above two. It is observed that the Nusselt number is increasing when characteristic length increases. In case of vertical orientation the characteristic length of ice block L= .12m. For horizontal orientation it is 0.035m and for cylindrical shape it is 0.092m.

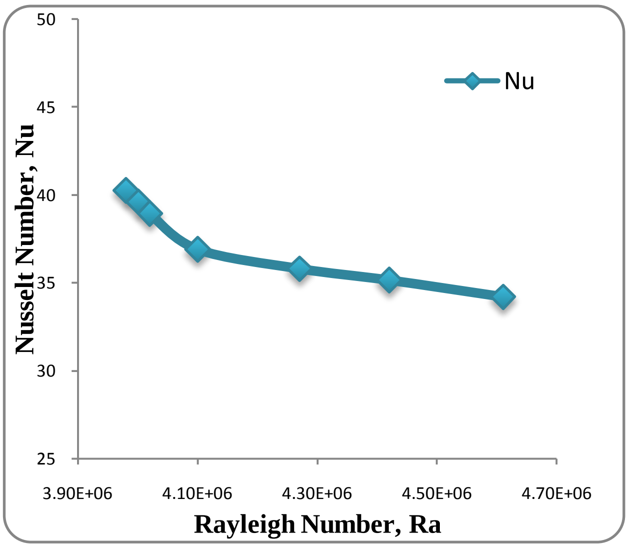

Figure 3. Variation of Nusselt number for vertical orientation

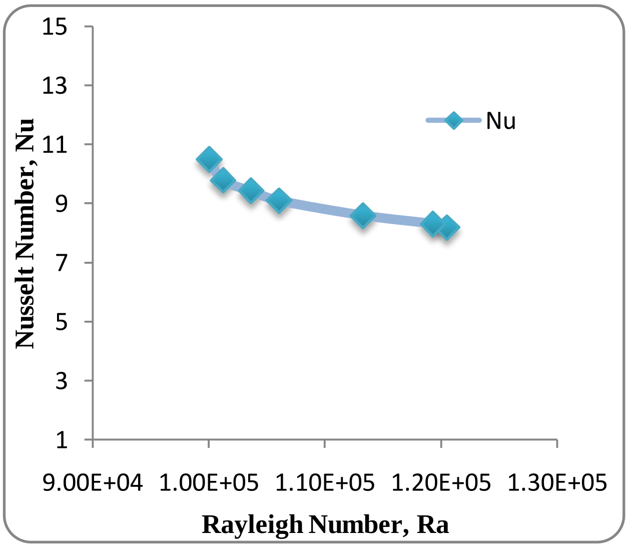

Figure 4. Variation of Nusselt number for horizontal orientation

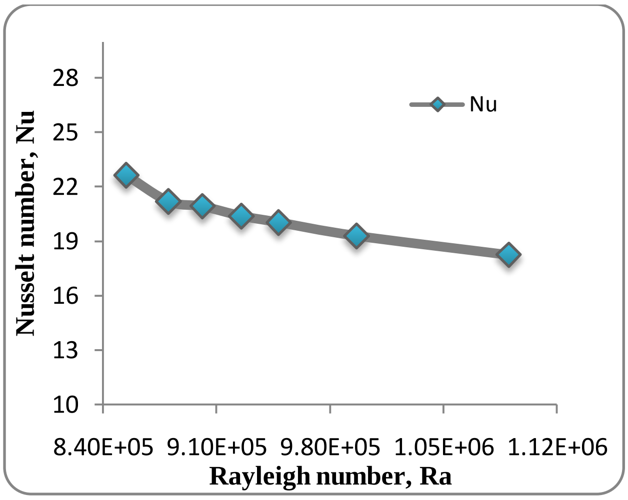

Figure 5. Variation of Nusselt number for cylindrical shape

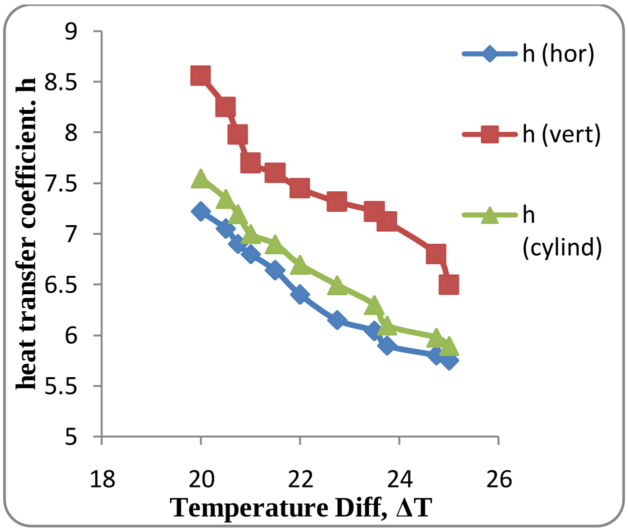

Figure 6. Variation of heat transfer coefficient

The variation of heat transfer coefficient is shown in fig 7. When heat transfer occurs in fluids the rate and total transfer are governed by several factors, two of which are easily known- temperature difference and area. Main factors that heat transfer coefficient depends are velocity of the fluid, orientation to the flow, geometric shape, surface condition, viscosity. In vertical orientation flow is more turbulent as compared to other because the plate is narrow, means length is high as compared to width. So the value of h is higher in that case. In that position or orientation the Ra value is higher, so that the flow is more turbulent. In horizontal orientation velocity of flow over the ice block is reduced due to that orientation. Value of h is low in this case as compared to other two. In case of cylindrical shape the surface is smoother as compared to rectangular shape. So the flow velocity may increase.

The results show that vertical orientation is more effective than horizontal orientation and cylindrical shape. When the width of the plate is relatively small compared to its height, i.e., the plate is narrow, the heat transfer rate can be considerably greater than that

predicted by these three-dimensional flow results. When relatively small vertical circular cylinders are used, the interactions of the flow over the surfaces that make up the cylinder have a considerable effect on the magnitude of the mean heat transfer rate and on the nature of the flow over the cylinder surfaces.

V. CONCLUSION

The following conclusion is derived from the detailed analysis presented in the result and Discussions.

1. Experimental study on natural convection over isothermal flat plate is conducted. Heat transfer coefficient in vertical orientation is higher than horizontal orientation.
2. When relatively circular cylinders are used, the interaction of the flow over the surfaces has a considerable effect on the magnitude of the mean heat transfer rate and on the nature of the flow over the cylinder surfaces.
3. So the heat transfer coefficient is little higher for cylindrical shape as compared to horizontal orientation.
4. From the comparison with changing the orientation from horizontal to vertical, it has an enhancement of 300% in average Nusselt number.
5. In case of cylindrical shape, there is an increase of average Nusselt number about 130% than in horizontal.
6. The characteristic length of the plate has a considerable effect on the heat transfer rate. This is because the temperature and velocity field do not end abruptly at the edge of the cold plate

VI. ACKNOWLEDGMENT

The authors wish to thank Department of Mechanical Engineering of College of Engineering Adoor for all the support for this work.

REFERENCES

[1] Lino R. C., Ramos D. M., and da Fontoura Rodrigues J. L. A. (2003), Natural Convection on Vertical Flat Plates: A Numerical and Experimental Study, 17th International Conference of Mechanical Engineering.

[2] Kobus C. J. and Wedekind G. L., An Experimental Investigation into Natural Convection Heat Transfer from Horizontal Isothermal Circular Discs, International Journal of Heat and Mass Transfer 44(2004), Pages 3381-3384.

[3] Azhar Kareem Mohammed , ZiyadJamilTalabani and Ramzi Raphael Ibraheem,Experimental Study of Steady State Natural Convection Heat Transfer From Cylindrical Heater in a Vented Enclosure ,Journal of Science and Engineering Vol. 2 (2), 2013, 87-96

[4] Comunelo R. and GuthsSaulo (2005), Natural Convection at Isothermal Vertical Plate: Neighbourhood Influence, 18th International Conference of Mechanical Engineering.

[5] Byung-ha kim, Seung-hwancho and Kap-jongriu, experimental investigation of natural convection from a horizontal ice surface melting in pure water, Experimental Heat Transfer 18 (1991) KSME Journal, VoI.5, No.2, 93-103.

[6] H.S Ttakharuniversity of manchestert,Free convection from a flat plate Fluid Mech. (1968), vol. 34, part 1, 81-89.

[7] Roslindanazar and Norsarahaidaamin,free convection boundary layer over non isothermal vertical flat plate, Journal Technology, 39(C) Dis. 2003: 61–74.

[8] Byzeevrotem and Hutzclaassen, Natural convection above unconfined horizontal surfaces Fluid Mech. (1969), vol. 38, part 1, 173-192.